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LONG WAVES IN AND NEAR THE SURF ZONE

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LONG WAVES IN AND NEAR THE SURF ZONE

by

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Lieutenant, United States Navy
B.S., Clarkson College of Technology, 1960

Submitted in partial fulfillment of the
requirements for the degree of

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PPER, J.

ABSTRACT

Four sets of field measurements were made of swell in and just seaward of the surf zone off a uniform sandy beach. Power spectra computed for both the pre-breakers and the foam lines revealed long waves associated with the swell having peak periods centered at approximately 80 seconds. Long wave records were produced by filtering out the ordinary swell through computing running means of the pre-breaker and foam-line records. Computer comparison of the long-wave records at the offshore and surf-zone sites for a given field run resulted in a time-correlation curve for various time lags between the records. Curves for all of the runs reveal that the long waves arrive from the open ocean, probably as forced waves travelling with swell groups, undergo reflection at the beach, and return back to sea as free waves.

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1. Research Objectives

The original objective of this research was to make field measurements of water-level fluctuations in the surf zone and to investigate their relationship to the breaker-zone foam lines. As the research proceeded, spectrum analysis of wave records made in and just seaward of the surf zone revealed two distinct peaks of wave energy. One was associated with the ordinary sea and swell and the other with sub-tidal long waves in the period range of one to two minutes. Attention was then focused on the nature and origin of the long waves. It is worth noting here that the writer could find no references in the literature to measurements of long waves made directly in the surf zone.

2. Description of the Area

Field observations were made on Del Monte Beach near the southern end of a long crescent-shaped sand beach which forms the inner shoreline of Monterey Bay. The area of study is shown in Figure 1, which is a section of Coast and Geodetic Survey Chart 5403. Del Monte beach is an excellent location for wave studies because of its uniformity and gentle slope, and the uniform bottom contours offshore. Due to the sheltered location of the beach, the dominant waves are low swell, but local wind waves generated by the coastal sea breeze and other onshore winds are common, particularly in the summer and fall seasons. Waves from the open ocean refract considerably and arrive with their crests parallel or nearly parallel to shore.

3. Field Instrumentation

Instrumentation from which the data used in this study were obtained includes: (1) a wave recorder located in a water depth of about

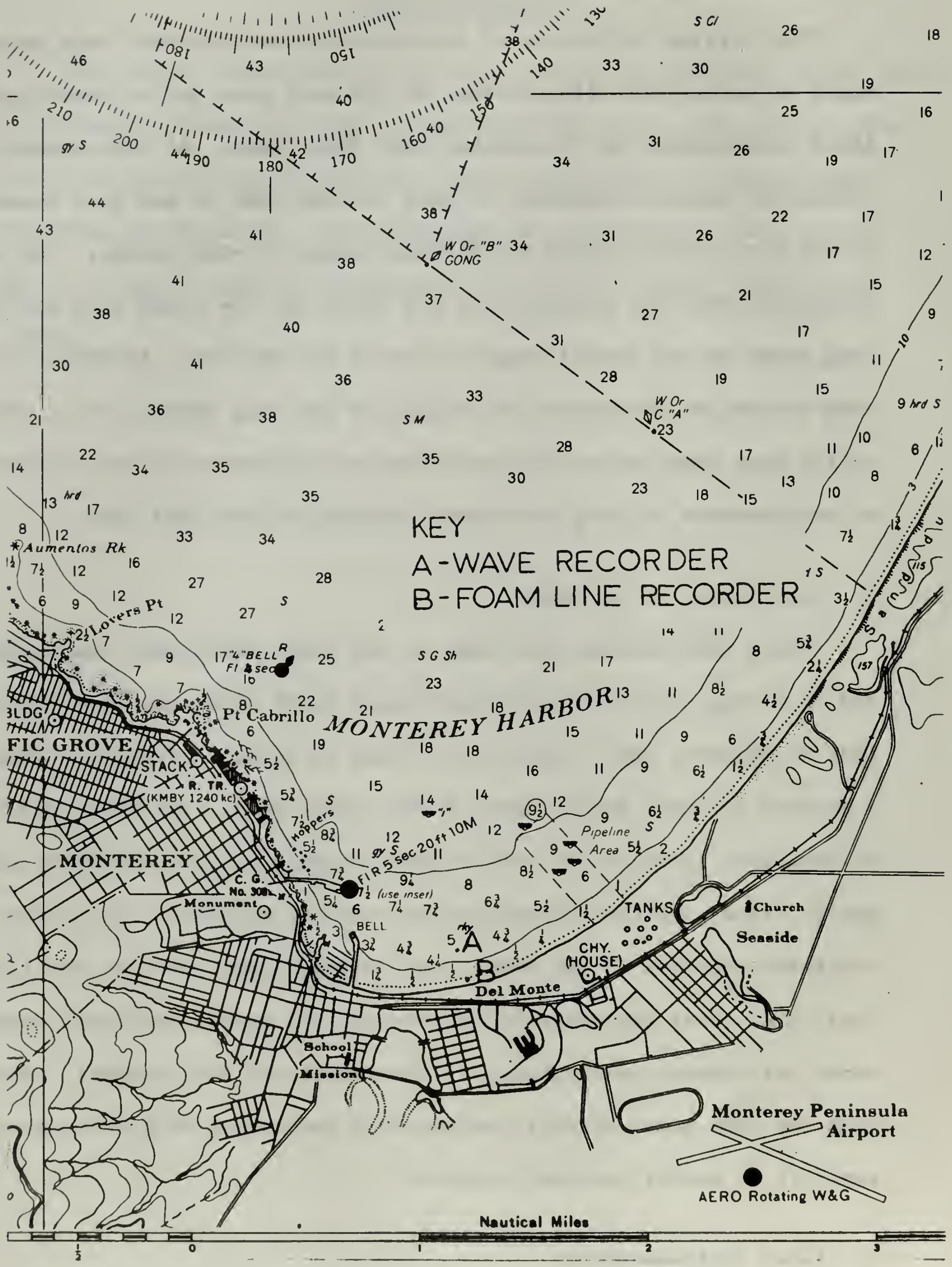

FIGURE 1: AREA OF STUDY

26 feet approximately 600 feet seaward of the surf zone, and (2) a device called a foam-line recorder placed in the surf zone directly inshore from the wave recorder. The relative locations of these instruments are shown in Figure 2. Ordinary sea and swell arriving from deep water passed the wave recorder as rotational waves, broke 500 to 700 feet inshore, then passed the foam-line recorder as translational waves or foam lines.

The wave sensor used offshore was a Snodgrass Mark IX pressure-type wave gauge. It incorporates a low-pass filter to eliminate the tides, but the instrument responds well to waves in the period range of at least several minutes. The recorder, located on shore, gave an analog wave trace on a strip chart.

The foam-line recorder, shown in the photographs in Figures 3 and 4, was designed and constructed by the investigator to measure the changing water levels in the surf zone. It is a float-type recorder consisting of three clear acrylic tubes, containing three-foot long floats. The tubes were mounted on a measuring staff graduated in tenths of feet, and the unit was secured to a rail driven in the beach about 1.7 feet above Mean Lower Low Water. Two of the tubes had restricted openings at the bottom so that they acted as high-frequency filters, whereas the third tube was completely open and its float responded to all water-level fluctuations. After processing the first set of wave data, it was evident that only the open tube data provided worthwhile information for this study.

Recording of the float oscillations in the open tube was achieved at two-second intervals through single-frame exposure of 16 mm movie film. Figure 5 depicts the recording setup, and shows the camera at the

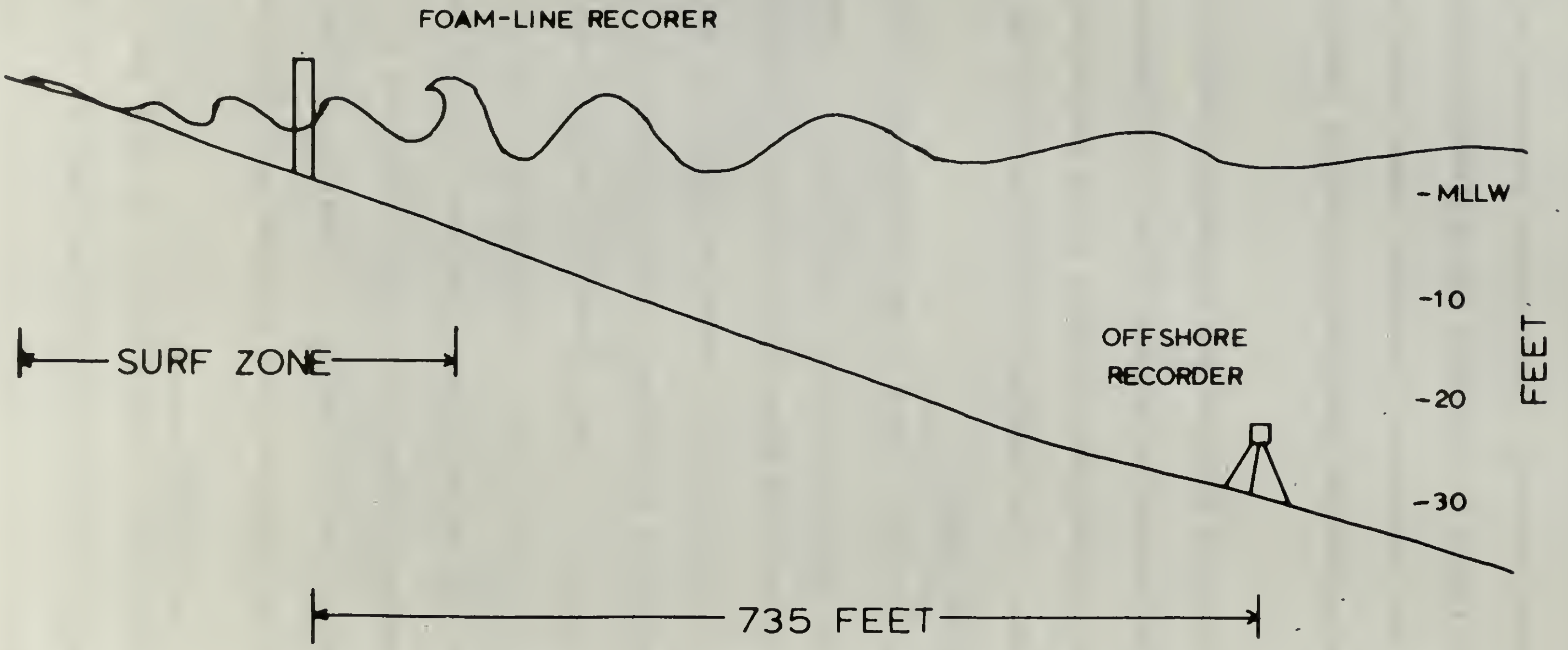

FIGURE 2: LOCATION OF WAVE SENSORS

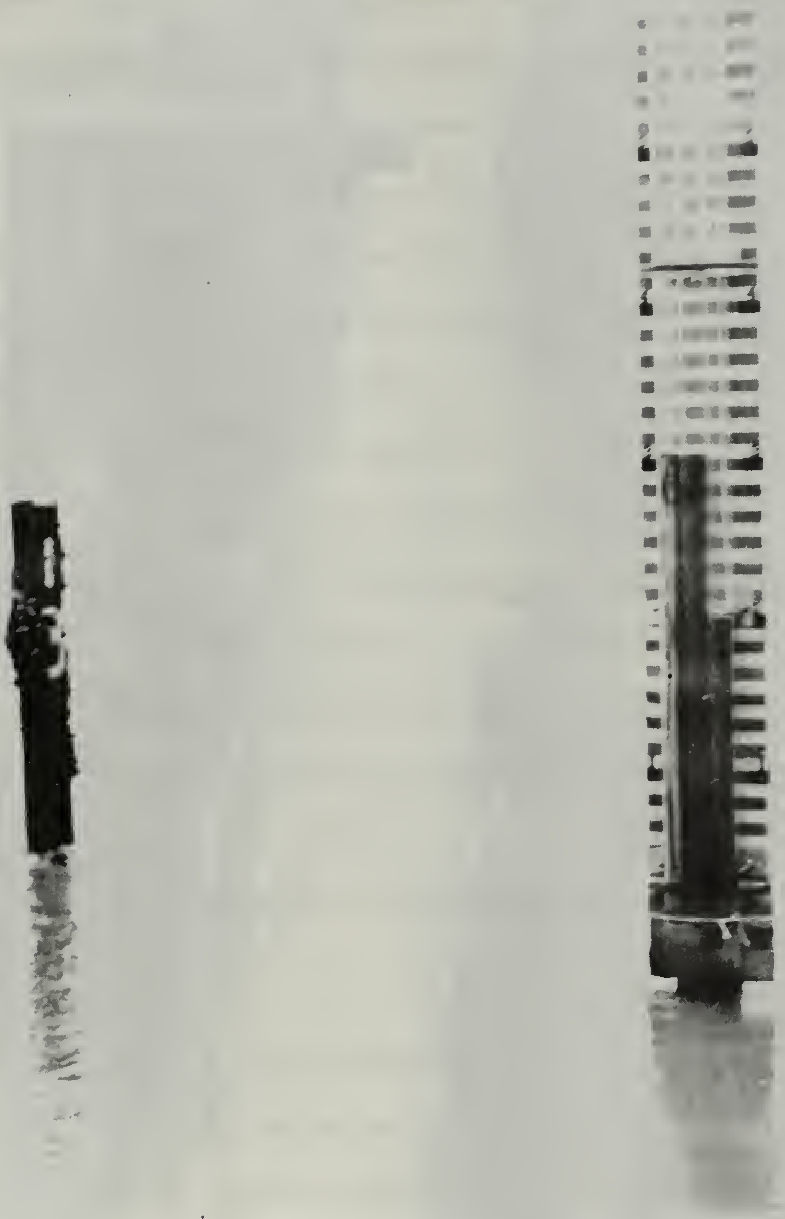

FIGURE 3: FOAM-LINE RECORDER

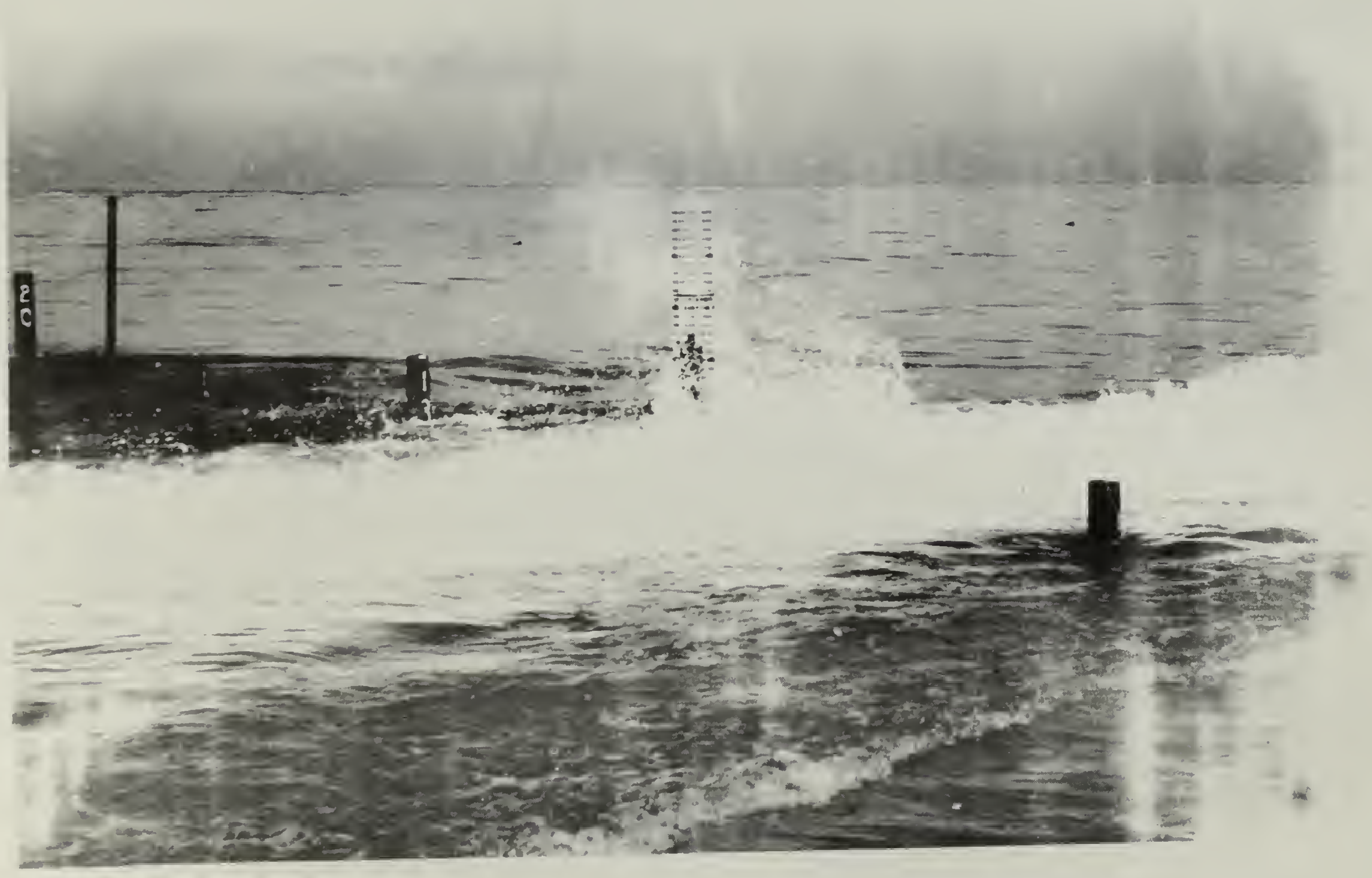

FIGURE 4: FOAM LINE PASSING RECORDER

far left directed at the foam-line recorder. The clock at the far right was placed on a tripod in the swash zone within the field of view of the camera during recording and served as a reference time for each frame of movie film. Excellent picture sharpness was attained through use of a 152 mm telephoto lens. Using projector and screen, float levels in the open tube for each set of wave observations were read to the nearest 0.01 foot. The readings were considered accurate to ±0.02 foot.

During a field run, the offshore wave gauge recorded the pre-breakers at the same time that the foam-line recorder was being photographed. The procedures also included synchronization of the two recordings. Because of the shoal water depths between the gauge and the recorder, waves of nearly all periods travel at approximately the shallow-water wave speed ($\sqrt{gd}$) and traverse the distance in about 32-36 seconds depending on the estimated average water depth. The duration of each set of field measurements was about 20-30 minutes so that for nearly all of the observational period individual waves observed to pass the wave recorder offshore were also recorded on the surf-zone recorder. The simultaneous records from the two instruments were then analyzed as described in the next section.

4. Data Reduction

Four sets of field measurements were made and the wave and tide conditions that prevailed during each are shown in Table 1. Unusually calm weather and low, uniform swell producing plunging breakers occurred in each case. These conditions are illustrated in the photograph in Figure 5. The initial (unrefracted) wave height, H_o', varied from 0.5 to 1.0 foot, and the initial wave steepness had a maximum value of 0.0052 ft/sec^2 for Run 3.

For purposes of computer processing, the wave records for each run

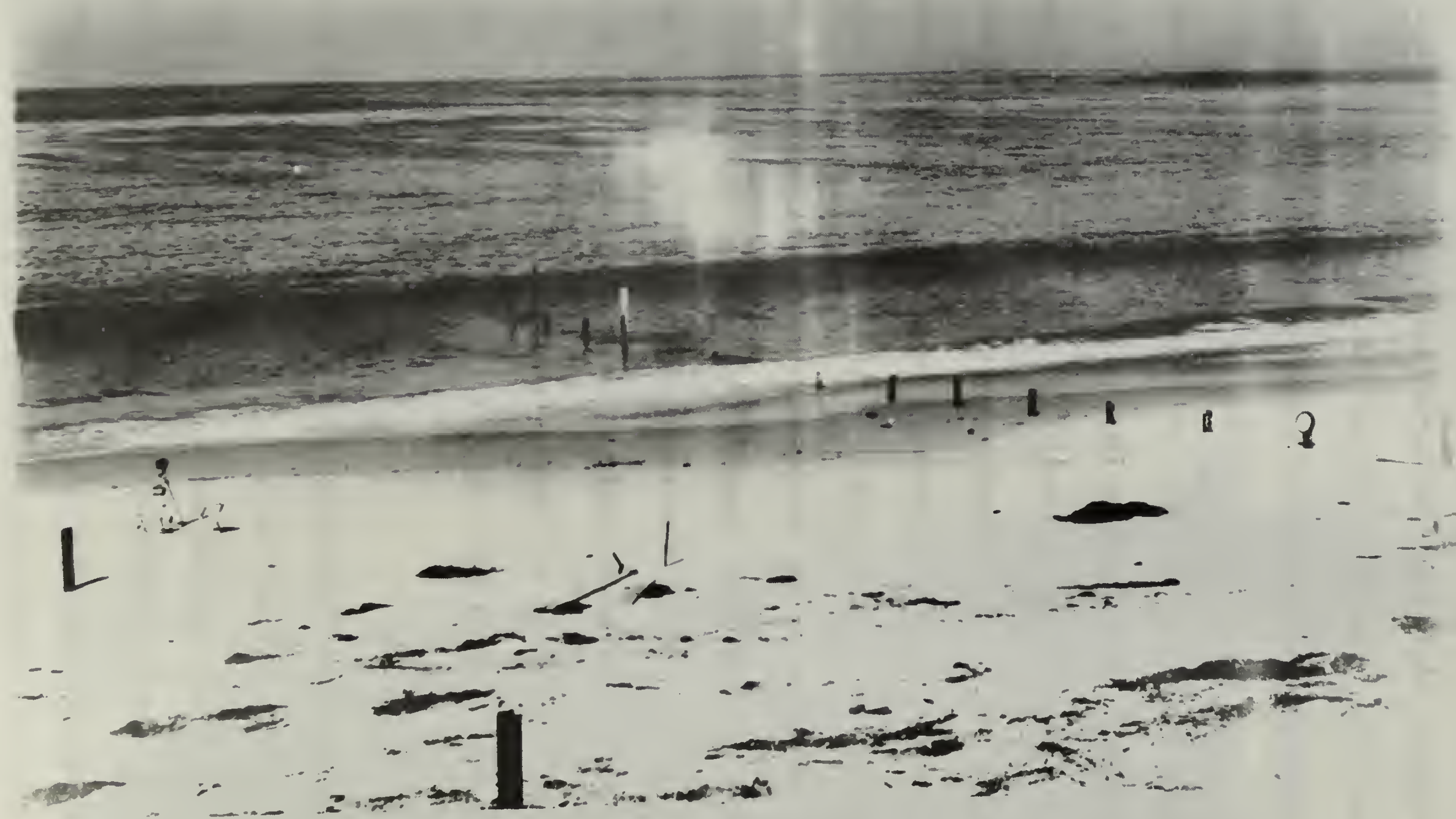

FIGURE 5: RECORDING EQUIPMENT

TABLE 1: WAVE AND TIDE CONDITIONS PREVAILING DURING FIELD RUNS

			Wave Condition Prevailing			Tide Condition Prevailing	
Wave Run	Date	Duration	Height (1)	Period	Steepness (2)	Height (3)	Stage
1	1 Mar 67	27 min	0.71 ft	14.3 sec	0.0035 ft/sec^2	3.7 ft	LHW
2	30 Mar 67	18	0.99	14.3	0.0048	3.7	LHW
3	1 Apr 67	18	0.76	12.1	0.0052	3.6	LHW
4	9 Apr 67	27	0.53	14.3	0.0026	3.1	2 Hours past HHW

(1) Unrefracted deep-water height, H_o'.

(2) Initial wave steepness is given as H_o'/T^2.

(3) Tide height is relative to Mean Lower Low Water (MLLW).

were needed in digital form. The data from the surf-zone gauge, recorded on movie film, were already in that form. The analog records from the offshore sensor were digitalized manually. Bottom records were analyzed without correction for hydrodynamic damping. Damping of long-period waves is negligible, and small for ordinary sea and swell. For convenience in computer comparison of the wave records from both instruments, the data-point interval used for all records was two seconds.

Processing of the data was accomplished with four programs written in FORTRAN 63 for a Control Data Corporation 1604 computer. Appendices I-IV list the individual programs, and the following are brief descriptions of each:

(1) POWSPEC. A spectrum analysis program based on the methods of Tukey and Blackman (1958) made available by the Naval Postgraduate School. It served to compute the power spectrum of the various wave records by calculating spectral densities in frequency steps of 0.0025 sec^{-1} over the frequency range from 0.00 to 0.25 sec^{-1}. A typical computer-drawn power spectrum is shown in Figure 6.

(2) PTPLOT. A program used to plot wave records for visual comparisons. It prints plotted data points along an abscissa having a fixed scale and an ordinate having a variable scale, which allowed rapid enlargement of wave records.

(3) RUNMWL. An elementary program written to compute and plot 12 and 14 second running means for various wave records. The significance of these time intervals is discussed in the next section. A portion of a plotted result for Run 3 appears in Figure 7, and shows a train of long waves derived from the wave record.

(4) HOWFIT. An elementary program used to calculate the similarity

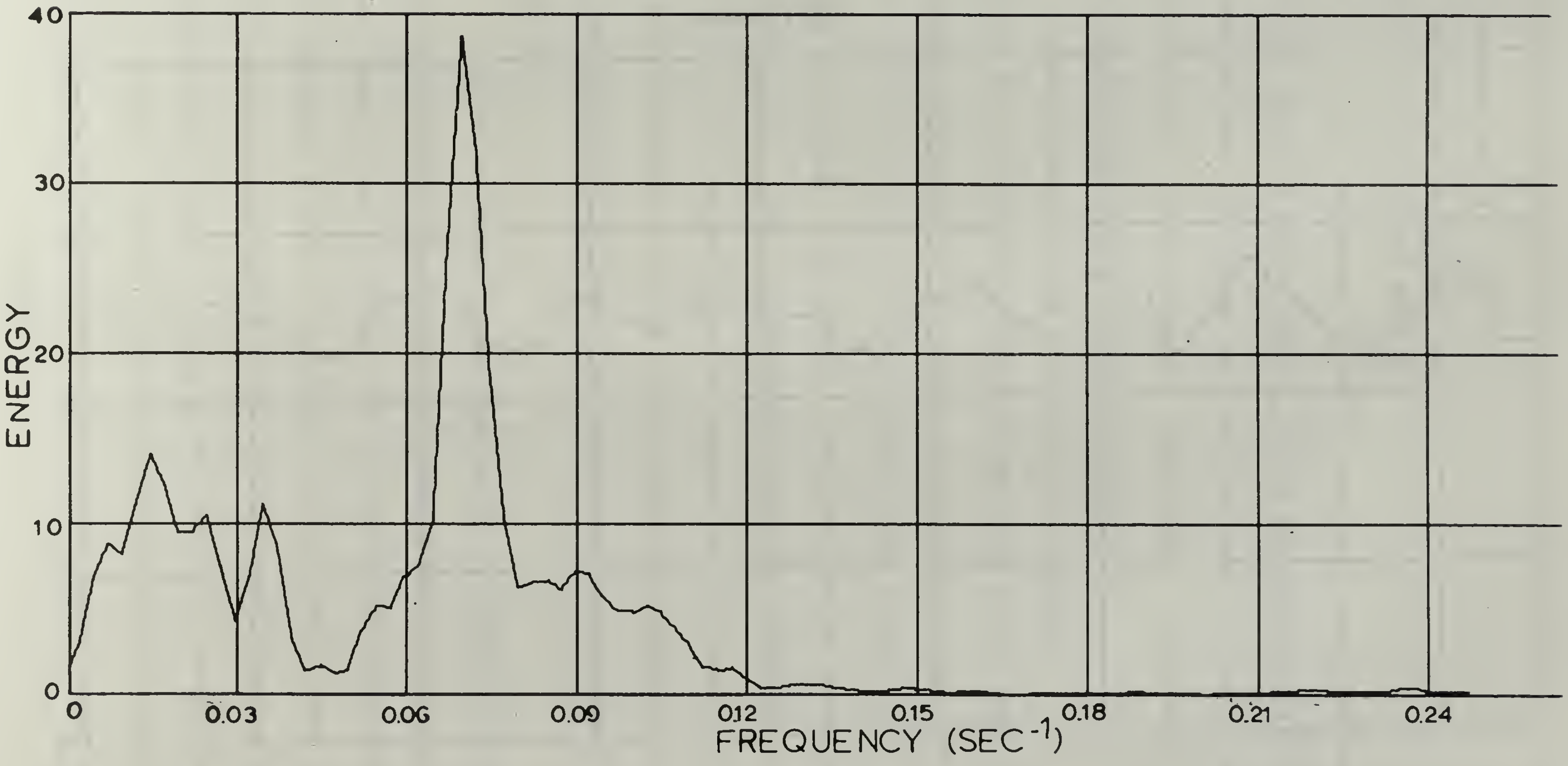

FIGURE 6: COMPUTER-DRAWN POWER SPECTRUM

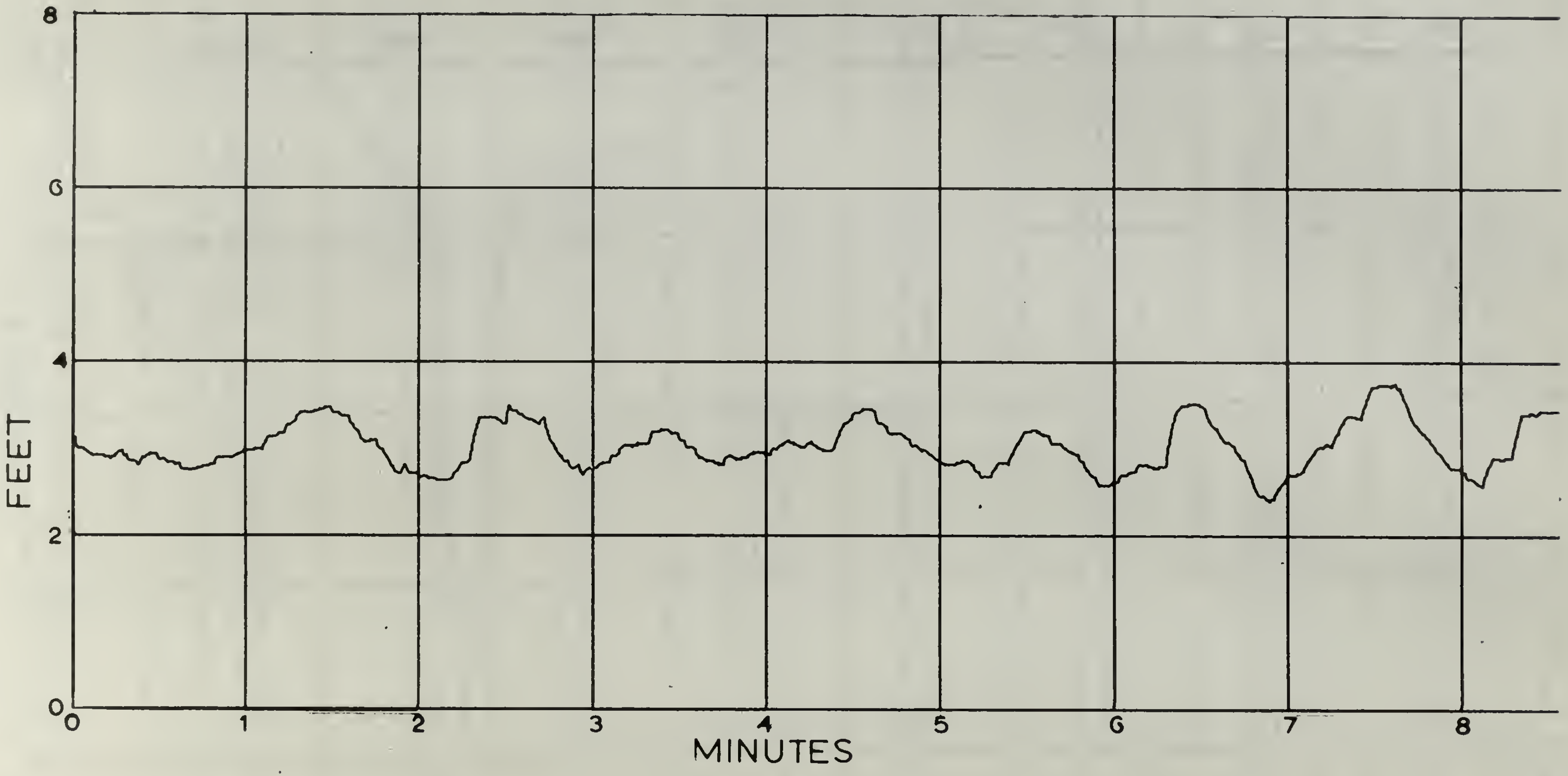

FIGURE 7: COMPUTER-DRAWN RUNNING MEAN

between wave records made offshore and in the surf zone. A discussion of this program appears later.

5. Analysis of a Selected Wave Run

To illustrate the manner in which wave data were processed, the wave records of Run 3 made on April 1 were selected arbitrarily for detailed examination. The waves were uniform long low swell, and displayed more prominent wave groups than the other runs. A portion of the record made at the offshore sensor is shown in Figure 8.

a. Waves Seaward of the Surf Zone (Pre-Breakers)

Figure 9 is the power spectrum of the wave record made at the offshore sensor during Run 3. It shows two distinct energy peaks, 32.9 ft^2 and 41.4 ft^2 at frequencies of 0.0825 and about 0.0125 sec^{-1}, or 12.1 and about 80 seconds, respectively. The short-period waves represent the ordinary swell. The longer-period waves are referred to as long waves. Due to the record's limited length and the computer program's 0.0025 sec^{-1} frequency interval, water-level oscillations of longer period could not be calculated from the record although they might have been present.

In an effort to describe the long waves in further detail, a 12-second running mean of the wave-record data points (at 2-second intervals) was computed and plotted. The purpose of the running mean is to act as a high-pass filter by averaging the wave record over 12-second intervals. It was intended that the ordinary swell, having approximately a 12-second period, would be largely filtered out, leaving the long waves in evidence. Figure 7 shows a portion of this running mean.

That the running mean wave record substantially represents the

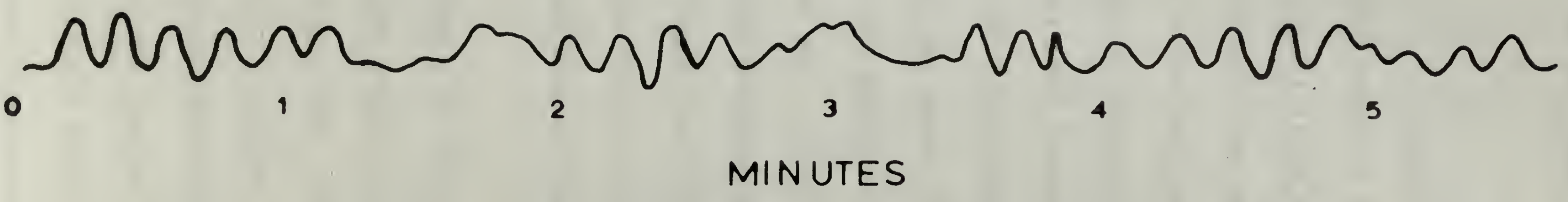

FIGURE 8: PRE-BREAKER RECORD: RUN 3

long-wave train passing the recorder is verified by spectral analysis of the running-mean record, also shown in Figure 9. Comparison of the spectra shows that the ordinary swell have been largely removed by averaging, but that high energy density remains at the long-wave period. For the 80-second period, a spectral density of 98.8 ft^2 was calculated, indicating a proportionately high concentration of long-wave energy.

For the two wave records the variance, V, was also computed. Applying the Pierson, Neumann and James (1955) wave theory, the significant wave height, H_s, (the average of the 1/3 highest waves) was calculated from $H_s = 2.83\sqrt{2V}$. For Run 3, the heights and periods of the pre-breakers were calculated as follows:

	Period	Height
Short waves (swell)	12.1 Seconds	0.82 Feet
Long waves	80 "	0.46 "

b. Waves in the Surf Zone (Foam Lines)

As a rotational wave approaches the surf zone it increases in height until it enters water approximately as deep as the wave is high, whereupon it becomes unstable and breaks. This new wave, a translational wave, is a type of bore commonly referred to as a foam line, which expends its energy rapidly in turbulence as it rolls towards the beach.

Through the use of a movie film run at a speed of 0.125 seconds per frame a detailed profile of a foam line's unique shape is shown in Figure 10. Encompassing a 13-second period, the wave displays its sharp turbulent front with a split-second one-foot rise in water level. The oscillations shown are largely the result of action of the float due to this turbulence. The float motion, which has a natural period of 1.5

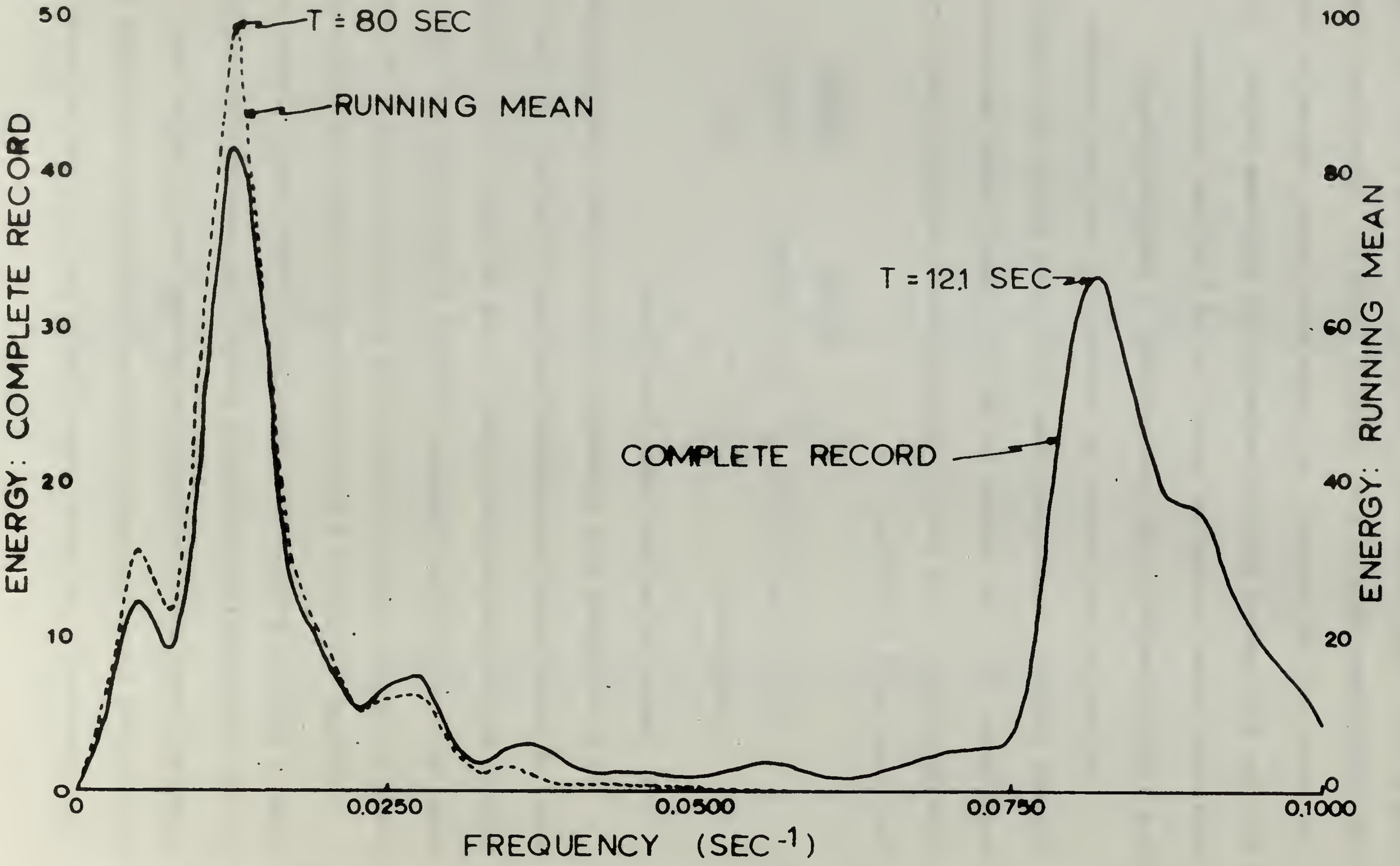

FIGURE 9: POWER SPECTRUM OF PRE-BREAKERS: RUN 3

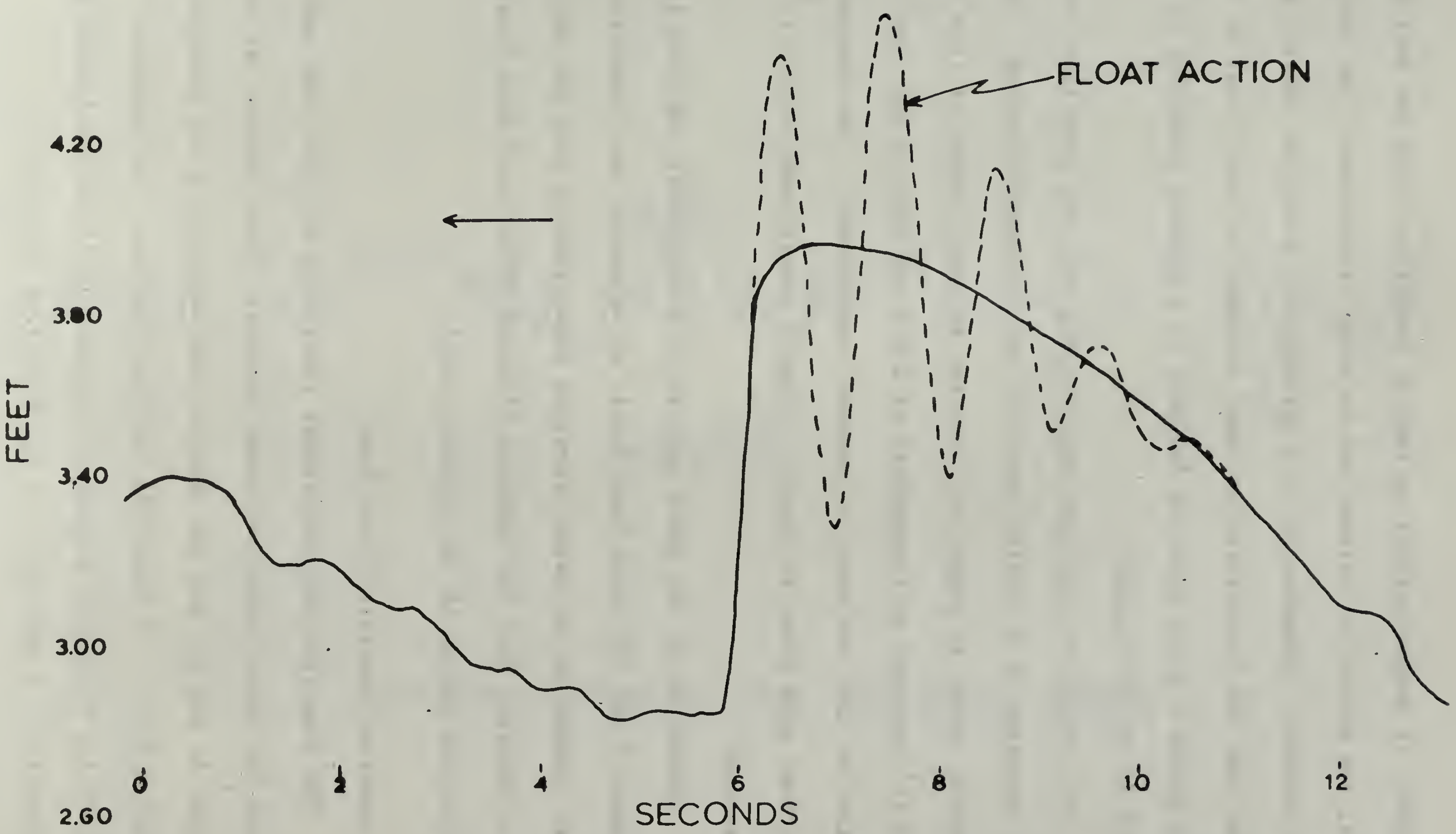

FIGURE 10: PROFILE OF TRANSLATIONAL WAVE

seconds, is damped quickly so that in comparison with the period of the wave, its effect is believed not to alter significantly the results from the recorder. Examination of a portion of a foam-line record, Figure 11, shows that the characteristic sharp increase in water level as the foam line passes a given point is followed by a gradual reduction of water level as the wave passes.

The record of surf-zone waves moving past the foam-line recorder was processed in a similar manner to the pre-breaker record. The power spectrum, shown in Figure 12, resulted in energy peaks of 12.0 ft^2 and 38.9 ft^2 centered at frequencies of 0.825 and about 0.015 sec^{-1}, or periods of 12.1 and about 67 seconds, respectively. The long-wave power spectrum, also shown in Figure 12, had a single peak of 76.9 ft^2 at about 67 seconds.

Comparison of the power spectra of pre-breakers and foam lines (Figures 9 and 12) shows that little or no energy was transferred to other frequencies as waves travelled from offshore into the surf zone. It is apparent that the breaking of waves in the surf zone considerably reduced the energy in the ordinary swell.

6. Spectral Analysis of All Runs

The foam-line and pre-breaker records of all four runs were processed for their respective power spectra. These spectra are shown in Figures 13 and 14, and the spectral characteristics are tabulated in Tables 2 and 3. In computing the power spectra, the equivalent equivariability bandwidth defined by Jenkins (1961) was used which provided frequencies $\pm$ 0.0025 sec^{-1} as the bandwidth boundaries.

Because a constant frequency step was used in computing the power

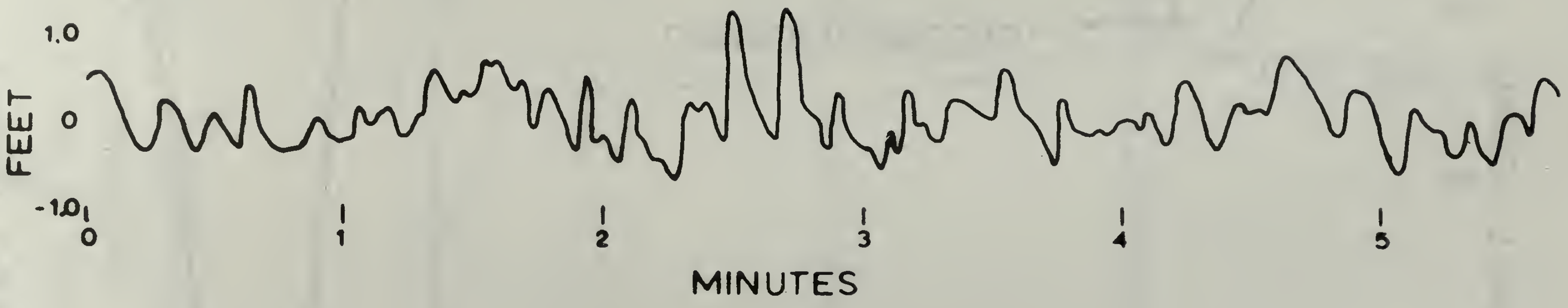

FIGURE 11: FOAM-LINE RECORD: RUN 3

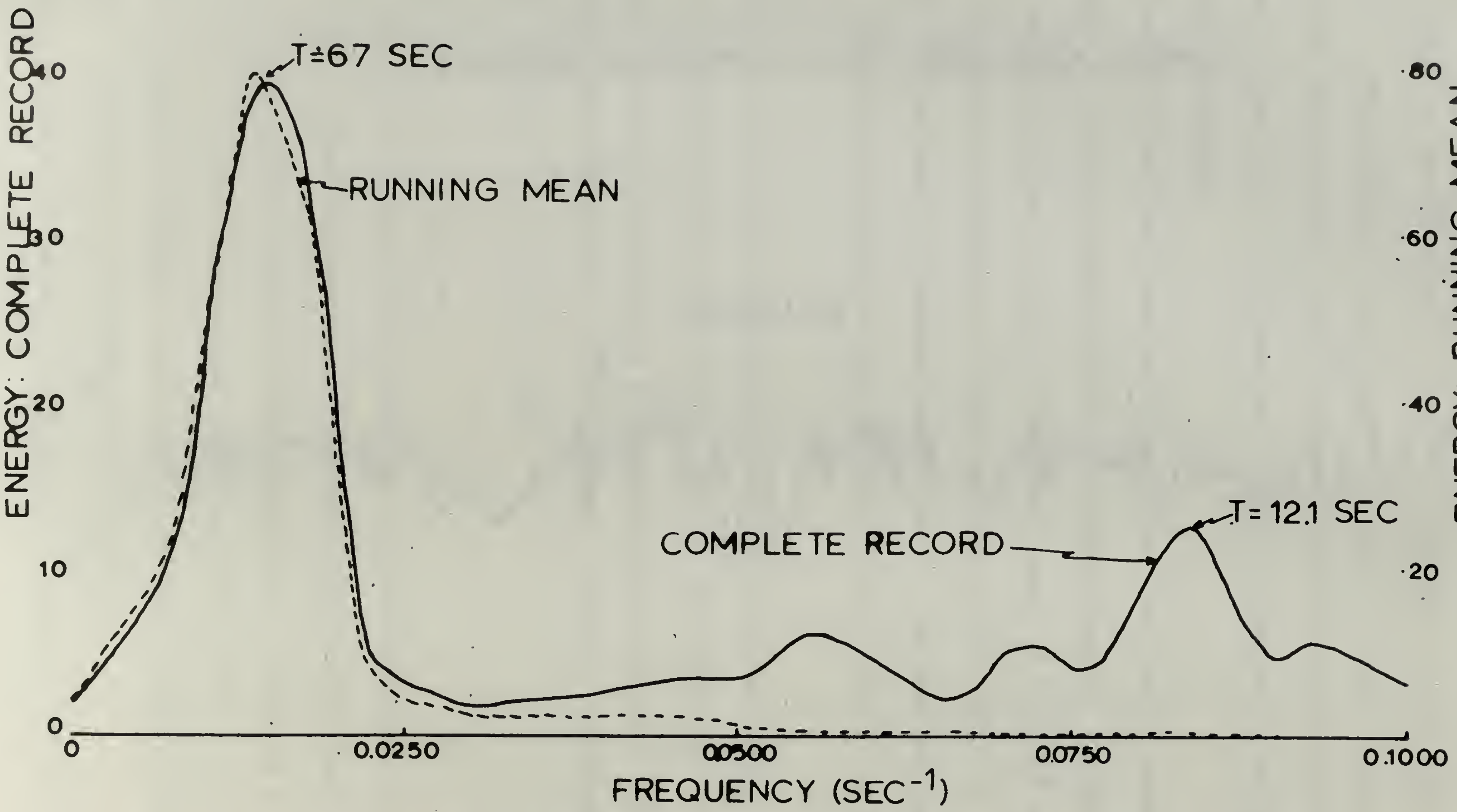

FIGURE 12: POWER SPECTRUM OF FOAM LINES: RUN 3

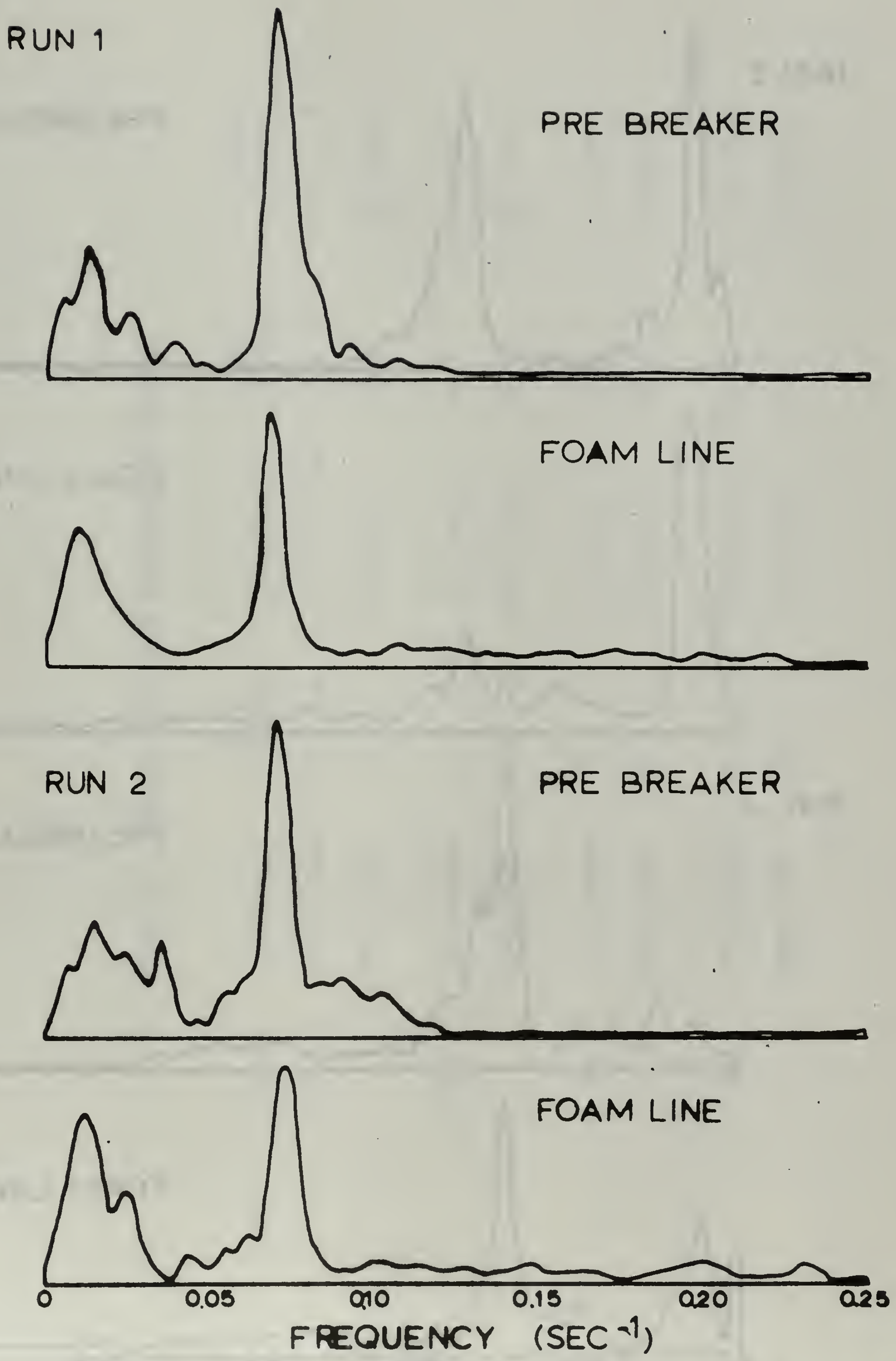

FIGURE 13: POWER SPECTRA: RUNS 1&2

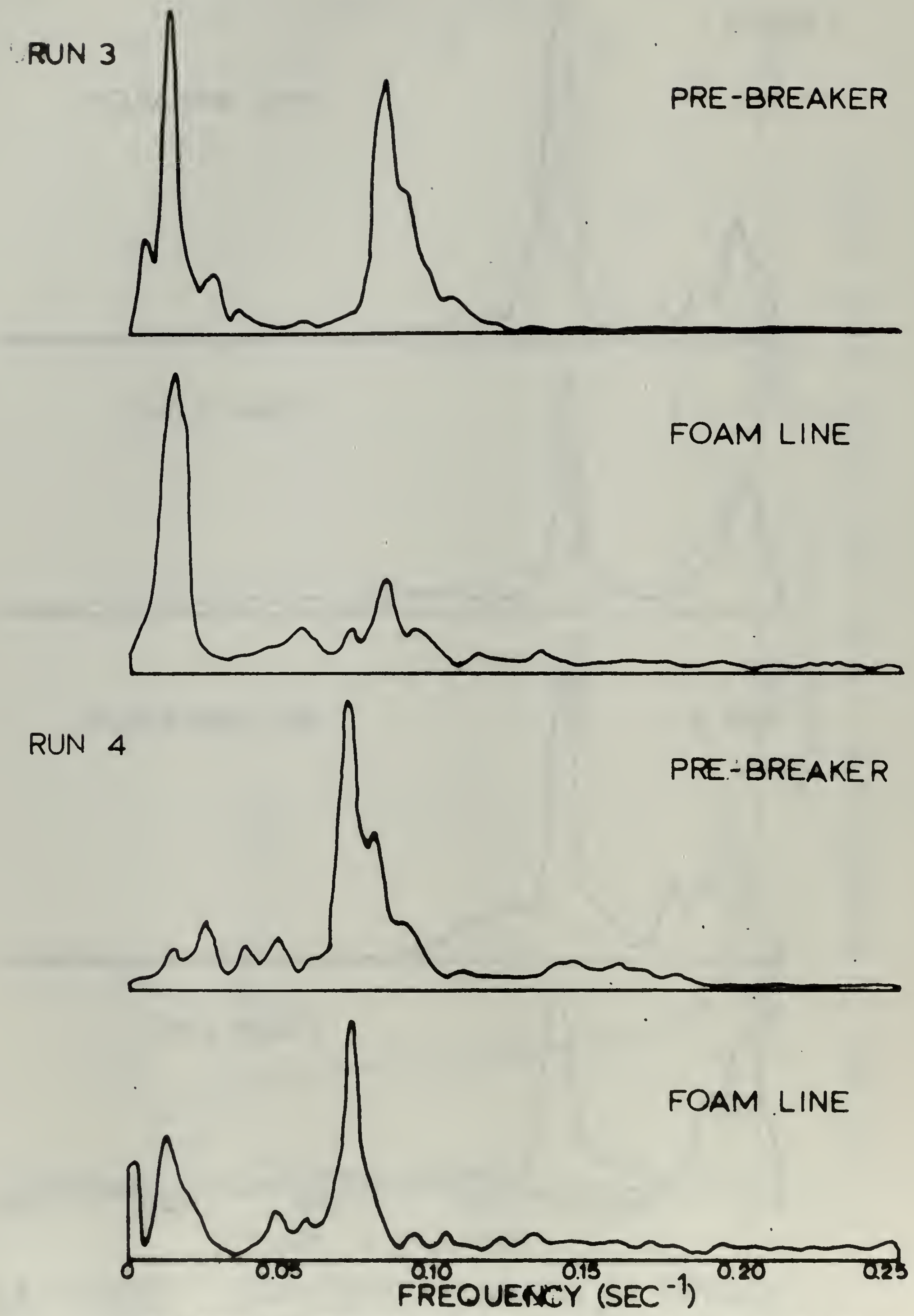

FIGURE 14: POWER SPECTRA: RUNS 3 & 4

TABLE 2: SPECTRAL DATA FOR SHORT WAVES (SWELL)

Run	Date	Record	Peak Period	Bandwidth	Peak Energy	Energy Levels
1	1 Mar	Pre-Breaker	14.3 sec	13.8-14.3 sec	45.1 ft^2	39.6-31.9 ft^2
		Foam Line	14.8	14.3-15.4	30.8	28.2-18.6
2	30 Mar	Pre-Breaker	14.3	13.8-14.8	38.7	32.4-28.7
		Foam Line	14.8	13.3-14.8	26.5	20.7-24.6
3	1 Apr	Pre-Breaker	12.1	11.8-12.5	32.9	24.7-28.7
		Foam Line	12.1	11.8-12.5	12.0	11.8-8.6
4	9 Apr	Pre-Breaker	14.3	13.8-14.3	37.1	36.4-18.6
		Foam Line	13.8	13.3-14.2	31.1	22.2-22.6

TABLE 3: SPECTRAL DATA FOR LONG WAVES

Run	Date	Record	Peak Period	Bandwidth	Peak Energy	Energy Levels
1	1 Mar	Pre-Breaker	80 sec	67-100 sec	16.1 ft^2	14.4-10.9 ft^2
		Foam Line	100	80-133	17.4	15.6-15.4
2	30 Mar	Pre-Breaker	67	57-80	14.7	12.4-11.2
		Foam Line	80	67-100	20.2	18.1-19.4
3	1 Apr	Pre-Breaker	80	67-100	41.4	27.0-23.5
		Foam Line	67	57-80	38.9	34.2-35.9
4	9 Apr	Pre-Breaker	40	36-44	7.9	6.0-6.7
		Foam Line	80	67-100	16.0	13.6-11.9

spectrum, the period bands were of variable width, and the resolution was best in the shortest periods. The longest period calculated was 400 seconds, the next shorter period was 200 seconds, then 133 seconds, etc., in decreasing steps down to 4 seconds. As a result of this non-linear scale, the peak periods of the long waves are less well-defined. A peak period of 80 seconds, for example, means that the peak could fall somewhere in the range from about 73 to 88 seconds.

The energy of the power spectrum for each wave record has been normalized so that the area under the curve equals one. Therefore, it is impossible to compare directly the magnitude of the peak energy of one record with that of another record. The peak energy values of a given train indicate only the relative amount of energy concentrated at the associated frequencies. The energy levels in Tables 2 and 3 are energy values lying on either side of the energy peak, and associated with the frequency limits of the bandwidth.

The most distinctive feature of Figures 13 and 14 is the dual peaks evident in seven of the eight records. In each of these records, peaks at periods of 12-14 seconds and 67-100 seconds occurred. In the eighth record, made at the offshore recorder on April 9, no well-defined long waves were found, but a slight increase in energy was noted about a 40-second period. The properties of the waves associated with the two energy peaks are summarized in Tables 2 and 3. The peak periods of the short waves (swell), in Table 2, remained relatively constant as the pre-breakers were transformed to foam lines. The swell bandwidth was about one second. The peak period of the long waves, in Table 3, was greater in the surf zone than at the offshore recorder in three of the four runs.

The relative amounts of energy contained in the bandwidths centered about the peak frequency of the short and long waves of each run are presented in Table 4. Short-wave and long-wave energy is defined here as the sum of the peak energy magnitude plus the energy levels on either side of the peak. The total bandwidth energy is the sum of the short and long wave energies. The relative percentages of the total energy contained in the short and the long waves are tabulated. As one would expect, energy was greater in the short waves than in the long waves, both offshore and in the surf zone, although there was one exception. It was found also that the percentages of short-period energy were greater in the pre-breakers than in the surf zone, and the long-period energy was consistently more important in the surf zone. These observations indicate that the short waves lose energy on breaking, hence the relative amount of long-wave energy increases.

The long waves isolated by the running means were treated in a similar manner, and the results are displayed in Table 5. Comparison with Tables 2 and 3 emphasizes the effectiveness of the running mean technique in filtering out the ordinary swell. The short periods were eliminated so thoroughly that in every case their "peak energy" was less than one. In seven records, the peak period of the running mean was that of the long wave revealed in the analysis of the complete wave record.

7. Investigation into the Nature of Long Waves

a. Background

Munk (1949) measured long waves of 2-5 minute period, which he termed "surf beat," and hypothesized a seaward direction of travel after

TABLE 4: SPECTRAL DATA COMPARISON

Run	Date	Record	Total Short-Wave Energy	Total Long-Wave Energy	Total Bandwidth Energy	% Short Wave Energy	% Long Wave Energy
1	1 Mar	Pre-Breaker	117.6 ft^2	41.4 ft^2	159.0 ft^2	74.0 ft^2	26.0 ft^2
		Foam Line	77.6	48.4	126.0	61.6	38.4
2	30 Mar	Pre-Breaker	96.8	38.3	135.1	71.7	28.3
		Foam Line	71.8	57.7	129.5	55.5	44.5
3	1 Apr	Pre-Breaker	86.5	81.9	168.4	51.4	48.6
		Foam Line	32.4	109.0	141.4	22.9	77.1
4	9 Apr	Pre-Breaker	92.1	20.6	112.7	81.7	18.3
		Foam Line	75.9	39.5	115.4	65.8	34.2

TABLE 5: SPECTRAL DATA FOR RUNNING MEANS

Run	Date	Record	Peak Period	Bandwidth	Peak Energy	Energy Limits
1	1 Mar	Pre-Breaker	80 sec	67-100 sec	58.4 ft^2	49.4-40.1 ft^2
		Foam-Line	100	80-133	59.1	50.8-53.4
2	30 Mar	Pre-Breaker	67	57-80	45.6	38.6-36.4
		Foam Line	100	80-133	53.5	53.2-39.5
3	1 Apr	Pre-Breaker	80	67-100	98.8	63.0-56.5
		Foam Line	67	57-80	76.9	64.2-72.4
4	9 Apr	Pre-Breaker	40	36-44	40.8	28.9-37.2
		Foam Line	80	66-100	61.0	50.1-46.0

radiation from the beach. Tucker (1950), studying similar waves, concluded that there is a correlation between the ordinary wave envelope and long waves moving seaward after an appropriate time lag. Later, Munk (1962) stated that new research showed the long waves moving shoreward, and not seaward. Tucker (1963) disagreed, and concluded that long waves are forced waves moving with the swell groups. This exchange serves to show that there exists a basic question concerning the direction of travel of long waves, and their relationship to the ordinary surface waves. Thus it became a purpose of this study to devise a method to compare the wave records of each run in order to learn the travel direction of the long waves.

b. Program HOWFIT

Program HOWFIT, Appendix IV, was written to calculate the degree of correlation between the long-wave components of the pre-breaker record and the surf-zone record of each run when offset in time by various amounts. Its task is best explained by the idealized wave records of Figure 15 representing the pre-breakers and foam lines from a given run. Case I illustrates a hypothetical situation in which two 20-minute water-level records, one from Station A offshore and the other from Station B in the surf zone, are frozen in time and placed one above the other. Visual comparison shows that the records do not match. This, of course, is expected since they were compared relative to the same time scale at two different locations. In Case II the record from Station B has been displaced forward in time relative to the record from Station A by the time it would take the dominant waves to travel from A to B. The records now present a closer match.

In order to determine the offset time intervals which give good

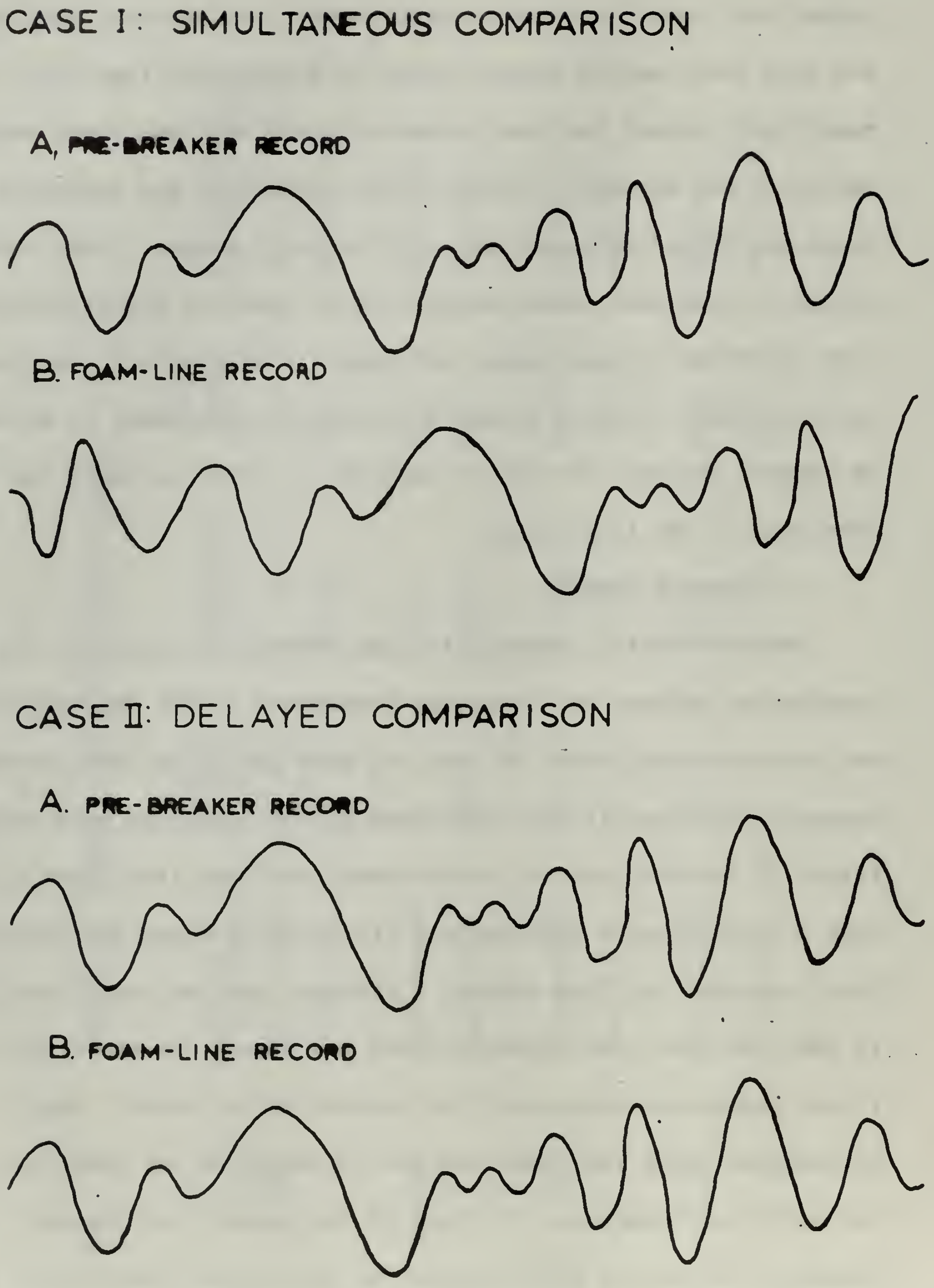

FIGURE 15: CORRELATION OF IDEALIZED WAVE RECORDS

correlations between two records, the following method was applied. The wave records were transformed to digital form having a two-second data-point interval. Then, beginning with an offset time of zero seconds between the records, the data-point differences between records were computed over an arbitrarily selected 12-minute time interval, the differences were squared, and then summed over the time interval to give a measure of the correlation. The process was then repeated after offsetting the surf-zone record from the pre-breaker record at two-second intervals both forward and backward in time between the limits of +180 and -180 seconds. These functions were performed by the HOWFIT program, and the result was a time-correlation graph for each pair of records.

Before HOWFIT could accomplish this task, it was necessary to prepare the records so that each set of wave trains was comparable, i.e., their amplitudes were equivalent and their means were equated to zero. The amplitude adjustment was made by multiplying the data points of each record by the square root of the other's variance. These steps were completed for both wave trains in each run before the sum of the least squares was computed.

Before discussing the results obtained, it is of interest to consider the travel time of shallow-water waves, both swell and long waves, between the recording devices. Recalling that the wave recorder was placed 735 feet directly seaward of the foam-line recorder, and considering the depth to average 12-15 feet between the sensors, a wave crest will transit the distance between sensors in about 33 to 37 seconds. These transit times are independent of the wave period for all waves dealt with in this study.

c. Time-Correlation Curves

In Figure 16, the reader can note at a glance certain features common to all of the curves. Each curve is centered roughly on the zero line, with minima of good correlation appearing on both sides of zero at time offsets approximately equal to the travel time of a long wave between the offshore recorder and the surf-zone recorder. This observation indicates that long waves come in from the open ocean and then are reflected from the shore back to sea.

The times of the correlation minima on either side of zero are listed in Table 6. Some of the variation between the values may be due to real travel-time differences of long waves moving shoreward versus moving seaward, but some variation may be due to slight errors in synchronizing the offshore record with the foam-line record, particularly in the case of Run 3. It may be noted that the time interval between the correlation minima is independent of errors in synchronization of the two records made during a given run.

The time-correlation curves in Figure 16 illustrate that the right-hand minimum represents a better correlation than the left-hand minimum in all runs. This means that a better correlation existed between long waves travelling from the surf zone to the offshore sensor, than for long waves moving shoreward. No explanation is offered for this interesting observation.

The general shapes of the time-correlation curves for Runs 1, 2, and 4 are similar, in that the best correlations occur near zero time and become generally worse as one increases the time separation. However, Run 3 is different in that good correlation between the two records occurs periodically as the time offset between the records is varied.

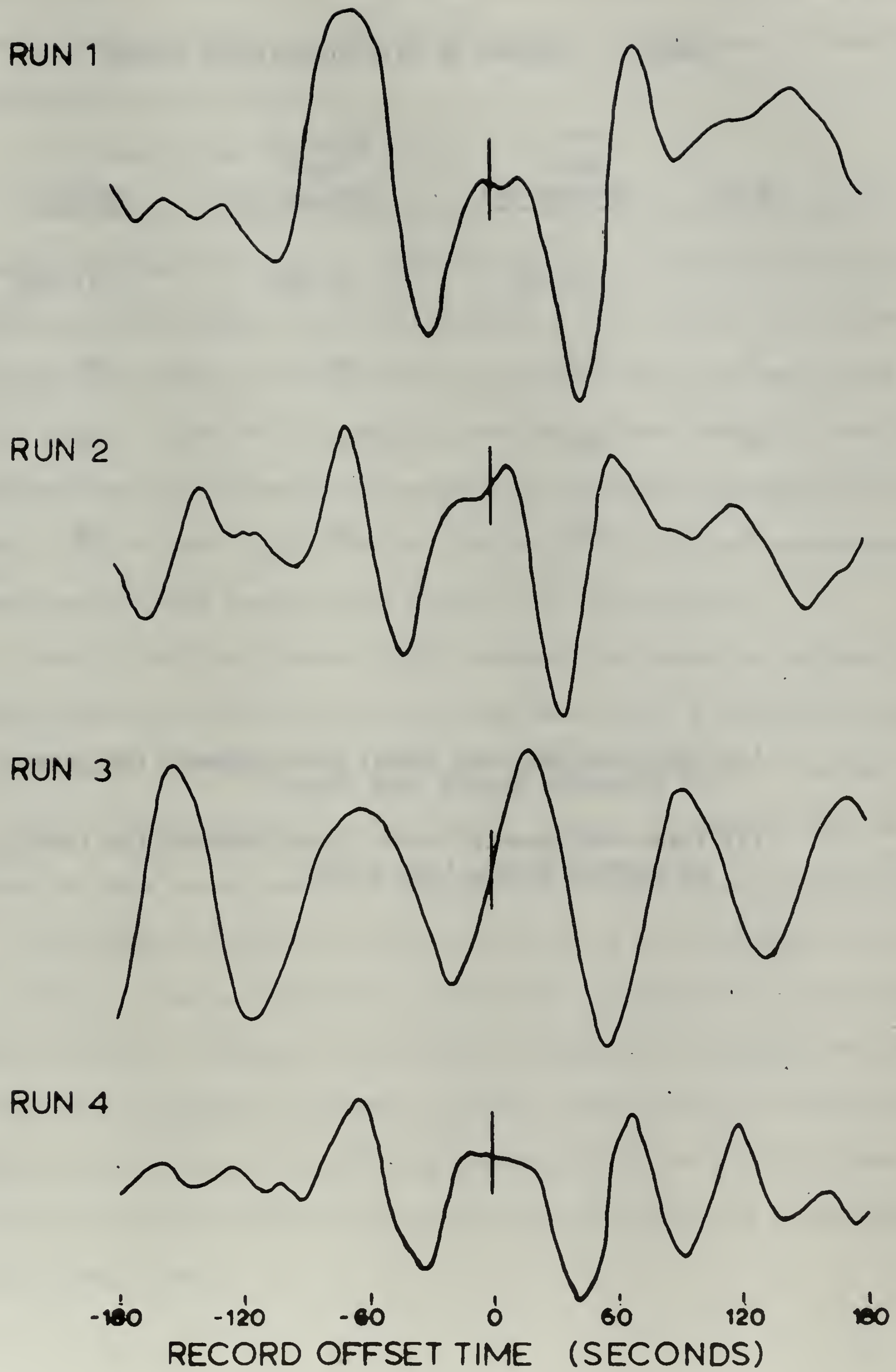

FIGURE 16: TIME-CORRELATION CURVES OF ALL RUNS

TABLE 6: SUMMARY OF TIME-CORRELATION CURVES

Run	Time of Left Minimum (1)	Time of Right Minimum (2)	Interval
1	-30 sec.	42 sec.	72 sec.
2	-42	34	76
3	-20	54	74
4	-36	40	76

(1) These are apparent travel times between the sensors of shoreward moving long waves.

(2) These are apparent travel times between the sensors of seaward moving long waves.

This appears to be due to the narrow spectral peaks of the long waves in Run 3, shown in Figures 9 and 12, and to near coincidence of their peak periods at the two sensors.

d. Other Aspects of Long Waves

Tucker's (1950, 1963) measurements and the theoretical work of Longuet-Higgins and Stewart (1962) stated that long-wave depressions are associated with high ordinary wave groups. As a part of this study, an attempt was made to associate the long waves with their respective short-wave groups. Time did not permit reduction of the necessary data to digital form for comparative purposes, so graphical interpretation was used. Due to the large amount of subjectivity in visual comparison of wave records, the results were found to be inconclusive.

Munk (1949) and Tucker (1950) measured long waves of periods two to five minutes outside the surf zone, and both found a rough 10:1 relationship between the heights of the short and the long waves. In this study a ratio of approximately 2:1 was found. Hence, it appears that the long waves of this report were not identical to those previously measured.

No effort was made to discover the nature of the reflective process as this is a complex subject in itself and is beyond the scope of this investigation. The same can be said regarding the origin of the long waves, but it appears probable, as Tucker (1962) stated, that the long waves are forced waves travelling shoreward with the ordinary wave groups. These forced waves then are reflected from the shore and travel back to sea as free waves.

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APPENDIX I: PROGRAM POWSPEC

```
      PROGRAM POWSPEC
C     TUKEY METHOD FOR ESTIMATING POWER SPECTRAL DENSITIES
      DIMENSION P(4000),A(600),X(600),FREQ(600),TAU(600),Q(3000)
      DIMENSION PER(600)
      DIMENSION KDATA(4000,2),IDENT(200)
      DIMENSION ITITLE(12)
      DIMENSION DATE(160),SKIP(160)
      COMMON KDATA
      EQUIVALENCE(KDATA,P)
C     FIRST STEP IS DATA CONTROL CARD--DATA READ IN BY CARD
      WRITE(6,103)
    1 READ (5,101) ITAPE,IDELTA,DELTAT,ISTART,IMAX,M
      READ (5,116) ABS,ORD,IWD,IHI
      WRITE(6,104)
      WRITE(6,101) ITAPE,IDELTA,DELTAT,ISTART,IMAX,M
      IQ=ISTART-1
      IADJ=IMAX-IQ
    2 CONTINUE
C     START DATA CARD READ IN--USE THIS BRANCH FOR TEST PURPOSES
    5 READ(5,102) (P(I),I=1,IMAX)
      WRITE(6,105)
      WRITE(6,106) (P(I),I=1,100)
      GO TO 30
   30 ASUM=0.0
   31 DO 32 I=1,IADJ,IDELTA
      ASUM=ASUM+P(I)
   32 CONTINUE
C     AZ IS NUMBER OF DATA SAMPLES BEING COMPUTED
      AZ=FLOATF((IADJ-1)/(IDELTA))+1.0
      ASUM=(ASUM)/(AZ)
   33 DO 34 I=1,IADJ,IDELTA
      P(I)=P(I)-ASUM
   34 CONTINUE
      ASIS=0.0
      DO 35 I=1,160
      DATE(I)=P(I)
      SKIP(I)=ASIS
      ASIS=ASIS+1.0
   35 CONTINUE
C     FIND MEAN SQUARE AZERO  I.E.AUTOCORRELATION AT TAU=ZERO
   40 ASUM=0.0
   41 DO 42 I=1,IADJ,IDELTA
      ASUM=ASUM+P(I)**2
   42 CONTINUE
      AZERO=ASUM/AZ
C     FIND AUTOCORRELATIONS A(L) FOR L=1,M
   43 DO 46 L=1,M
      ASUM=0.0
      BSUM=0.0
      CSUM=0.0
      MZ=(L*IDELTA+1)
   44 DO 45 I=MZ,IADJ,IDELTA
      IZ=I-(L*IDELTA)
      ASUM=ASUM+P(IZ)*P(I)
      BSUM=BSUM+P(IZ)
      CSUM=CSUM+P(I)
   45 CONTINUE
      AZ=(1.0)/FLOATF(((IADJ-1)/(IDELTA))+1-L)
      A(L)=(AZ)*(ASUM)-(AZ**2)*BSUM*CSUM
   46 CONTINUE
C     FIND XZERO---POWER SPECTRAL DENSITY AT FREQ=ZERO
   50 ASUM=0.0
      MZ=M-1
      FM=FLOATF(M)
      CS1=COSF(3.14159/FM)
      SN1=SINF(3.14159/FM)
      CSL=CS1
      SNL=SN1
   51 DO 52 L=1,MZ
C     AZ=HANNING FACTOR
C     FIND COSINE SUM FROM TRIG. IDENTITIES
      AZ=1.0+CSL
      ASUM=ASUM+AZ*A(L)
      CSL1=CSL*CS1-SNL*SN1
      SNL1=SNL*CS1+CSL*SN1
      CSL=CSL1
      SNL=SNL1
   52 CONTINUE
      DZ= .5/FM
      XZERO=DZ*(ASUM+AZERO)
C     FIND X(K)---POWER SPECTRUM AT K=1,M
      CSK=CS1
      SNK=SN1
   53 DO 59 K=1,M
      ASUM=0.0
      CSKL=CSK
      SNKL=SNK
      CSL=CS1
      SNL=SN1
   54 DO 55 L=1,MZ
      AZ=(1.0+CSL)*CSKL
      ASUM=ASUM+AZ*A(L)
      CSL1=CSL*CS1-SNL*SN1
      SNL1=SNL*CS1+CSL*SN1
      CSL=CSL1
      SNL=SNL1
      CSKL1=CSKL*CSK-SNKL*SNK
      SNKL1=SNKL*CSK+CSKL*SNK
      CSKL=CSKL1
      SNKL=SNKL1
   55 CONTINUE
      IF (K-M)56,57,57
   56 DZ=1.0
      GO TO 58
   57 DZ= .5
      GO TO 58
   58 DZ=DZ/FM
      X(K)=DZ*(ASUM+AZERO)
      CSK1=CSK*CS1-SNK*SN1
      SNK1=SNK*CS1+CSK*SN1
      CSK=CSK1
      SNK=SNK1
   59 CONTINUE
C     SHIFT INDICES--ZERO FREQ WILL START AT K=1 AFTER SHIFT
C     USE STORAGE SPACE OF P(I) DATA DURING SHIFT OPERATION
C     NORMALIZE AUTOCORRELATION
C     NORMALIZE AUTOCORRELATION W.R.T. AZERO
   60 DO 61 I=1,M
      P(I 1)=X(I)
      P(I 1001)=A(I)
   61 CONTINUE
      X(1)=XZERO
      A(1)=1.0
      MZ=M+1
   62 DO 63 I=2,MZ
      X(I)=P(I)
      A(I)=P(I+1000)/(AZERO)
   63 CONTINUE
C     APPLY TRAPEZOIDAL RULE TO FIND ENERGY CONTAINED IN POWER SPECTRUM
C     FOR RANGE OF K=1,M+1---DEFINE ENERGY AS XENGY
C     NOTE X(K) IS ENERGY W.R.T. UNIT CHANGE OF INDEX K
      ASUM=0.0
   65 DO 66 K=2,M
      ASUM=ASUM+X(K)
   66 CONTINUE
      XENGY=0.5*(X(1)+2.*ASUM+X(M+1))
C     FIND FRACT+ON OF TOTAL ENERGY IN CALCULATED FREQ. RANGE
      XFACT=XENGY/AZERO
C     OBTAIN SPECTRAL DENSITY W.R.T. FREQ(CPS)--NORMALIZE W.R.T. XENGY
      FREQ(1)=0.0
      TAU(1)=0.0
      PER(1)=1.0
      MZ=M+1
   67 DO 68 K=1,MZ
```

```
      AZ=2.0*(DELTAT)*FM
      X(K)=(AZ)*X(K)/XENGY
      FREQ(K+1)=FREQ(K)+(1.0)/(AZ)
      PER(K+1)=1.0/FREQ(K+1)
      TAU(K+1)=TAU(K)+DELTAT
   68 CONTINUE
C     POWER SPECTRUM WRITE OUT INSTRUCTIONS
   70 WRITE (6,103)
      WRITE(6,107) XFACT,AZERO
      WRITE(6,108)
      WRITE(6,109)(TAU(K),A(K),FREQ(K),X(K),PER(K),K=1,MZ)
      LABEL = 4H
      ITITLE(1)=8HHOPPER
      ITITLE(2)=8HPOWER SP
      ITITLE(3)=8HECTRUM F
      ITITLE(4)=8HOR WAVE
      ITITLE(5)=8HRECORDER
      ITITLE(6)=8H DATA OF
      READ (5,115) ITITLE(7)
      DO 80 J=8,12
   80 ITITLE (J)=8H
      CALLDRAW(M,FREQ,X,0,0,LABEL,ITITLE,ABS,ORD,0,0,2,2,IWD,IHI,1,LAST)
  500 CONTINUE
  101 FORMAT(2I3,F4.1,3I3)
  102 FORMAT(16F5.2)
  103 FORMAT (99H1 T U K E Y   S P E C T R U M   E S T I M A T E S,
     1POWER SPECTRAL DENSITY AND AUTO-CORR. CALCS.      //)
  104 FORMAT (20H  DATA CONTROL CARD  //)
  105 FORMAT (30H0 DATA RECORD--(P(I)=1,100)       //)
  106 FORMAT (10F8.3)
  107 FORMAT (8H XFACT= F8.5,8H  A(0)= F12.5  //)
  108 FORMAT (51H TAU(SEC)  AN(TAU)    FREQ(CPS)  XN(FREQ)  PER(SEC)//)
  109 FORMAT (1X,F5.1,F10.5,F12.5,F10.5,F10.3)
  110 FORMAT (3X,I4)
  111 FORMAT (3X,O16)
  112 FORMAT (31H1  ERROR IN SR DATA AT HEADING )
  113 FORMAT (40X,I3,7X,O16)
  114 FORMAT (22H  IDENT(N),N=1,NUMHDR  //)
  115 FORMAT (A8)
  116 FORMAT (F6.2,F6.2,2I3)
      END
      END
         FINIS
-EXECUTE.
```

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APPENDIX II: PROGRAM PTPLOT

```
      PROGRAM PTPLOT
      DIMENSION X(900), Y(900)
      K = 812
      READ 115, (Y(I), I=1,K)
  115 FORMAT (16F5.2)
      DO 2 I=1,K
    2 X(I) = I
      CALL PTPLOT ( X, Y, K)
      END
      SUBROUTINE PTPLOT ( X, Y, K)
       DIMENSION X(900), Y(900), LARK(113), MARK(90)
      IF (K-813) 1,2,2
    2 WRITE(51,100)
  100 FORMAT( 20X,  10HK TOO BIG.)
      GO TO 99
    1 KK = K + 1
      X(KK) = X(K) - 1.0
      BIG = Y(1)
      SMALL = Y(1)
      DO  3  M = 2,K
      IF ( BIG - Y(M) ) 4,5,5
    4 BIG = Y(M)
      GO TO 3
    5 IF ( SMALL - Y(M) )  3,3,24
   24 SMALL = Y(M)
    3 CONTINUE
      SPAN = BIG - SMALL
      IF ( SPAN ) 6, 22, 6
   22 WRITE (51, 150 )
  150 FORMAT ( 40HNO GRAPH SINCE MIN AND MAX ARE THE SAME.  )
      GO TO 99
    6 DO 7 I = 1, 113
    7 LARK(I) = 1H.
      WRITE(51,200), LARK
  200 FORMAT ( 1H1, 113A1)
      WRITE (51,300), SMALL,BIG
  300 FORMAT (1X,1H.,F10.4,51X,F10.4,1H.,28X,1H.)
      LAX = 0
      IF ( SMALL ) 8,9,9
    8 IF ( BIG ) 9,10,10
   10 LAY = (((ABSF (SMALL))/ SPAN) * 89.0) + 1.0
      GO TO 11
    9 LAY = 0
   11 DO 12 M = 1,K
      N = M + 1
      LY = ((( Y(M) - SMALL) / SPAN) * 89.0) + 1.0
      DO 20 II = 1, 90
   20 MARK (II) = 1H
      IF ( LAX - M ) 19, 14, 19
   19 IF ( X(M) ) 13,14,15
   13 IF ( X(N) ) 16,17,18
   15 IF ( X(N) ) 18,17,16
   18 IF(( ABSF ( X(M)))  - (ABSF ( X(N) )) ) 14,14,17
   14 DO 23 JJ = 1, 90
   23 MARK (JJ) = 1H.
      GO TO 21
   17 LAX = N
      GO TO 21
   16 LAX = 0
   21 MARK ( LAY) = 1H.
      MARK (LY) = 1H+
      WRITE(51,400), MARK,X(M),Y(M)
  400 FORMAT(1X, 1H., 90A1, 1H., 2F10.2, 1H.)
   12 CONTINUE
      WRITE(51,500),LARK
  500 FORMAT ( 1X,  113A1)
   99 RETURN
      END
      END
         FINIS
-EXECUTE.
```

APPENDIX III: PROGRAM RUNMWL

```
      PROGRAM RUNMWL
      DIMENSION X(1000),ITITLE(12),BAR(9   ),G(900)
      READ 5,M
    5 FORMAT (1I3)
   30 READ 18,(X(I),I=1,810)
   18 FORMAT(16F5.2)
   33 PRINT 72
   72 FORMAT  (1H1,27X,41HRUNNING MEAN CALCULATIONS FOR WAVE RECORD
     116H OF 1 MARCH DATA//27X,16HMEAN WATER LEVEL)
      PRINT 5, M
      DO 200 L=1,3
      KE=L*270
      KB=KE-269
      DO 203 K=KB,KE
      G(K) = K-270*(L-1)
      BARX=0.
      SSQ=0.
      YN=M
      JF = K
      IF (K-804) 37,35,35
   35 GO TO 204
   37 CONTINUE
      JL=K+6
      DO 43 J=JF,JL
      BARX=BARX+X(J)
   43 CONTINUE
      BARX=BARX/YN
      BAR(K)=BARX
      PRINT 55,BARX
   55 FORMAT (33X,F6.3)
  203 CONTINUE
  204 LABEL = 4H
      ITITLE(1)=8HHOPPER 1
      ITITLE(2)=8H4 SECOND
      ITITLE(3)=8H RUNNING
      ITITLE(4)=8H MEAN FO
      ITITLE(5)=8HR WAVE R
      ITITLE(6)=8HECORD OF
      ITITLE(7)=8H1 MAR 67
      ITITLE(8)=8H
      ITITLE(9)=8H
      ITITLE(10)=8H
      ITITLE(11)=8H
      GO TO (50,60,70)L
   50 READ (5,115) ITITLE (12)
      K = 270
      GO TO 80
   60 READ (5,116) ITITLE (12)
      K = 270
      GO TO 80
   70 READ (5,117) ITITLE (12)
      K = 264
   80 CALLDRAW(  K,G(KB),BAR(KB),0,0,LABEL,ITITLE,30.,2.,0,0,2,2,9, 7,1,
     1LAST)
  200 CONTINUE
  115 FORMAT (A8)
  116 FORMAT (A8)
  117 FORMAT (A8)
      STOP
      END
      END
         FINIS
-EXECUTE.
  7
PAGE ONE
PAGE TWO
```

APPENDIX IV: PROGRAM HOWFIT

```
      PROGRAM HOWFIT
      DIMENSION X(900), Y(900), DIFF(900), SUM(900)
    3 READ (5,5) N,M
    5 FORMAT (2I3)
      READ(5,8)  FMWLX, FMWLY, WRV, FLV
    8 FORMAT  4F5.2
      READ (5,28) (X(K),K = 1,N)
      READ (5,18) (Y(K), K = 1,N
   18 FORMAT(16F5.2)
   28 FORMAT(16F5.2)
      L = 180
      DO 30 K = 1,N
      X( K) =  X(K) - FMWLX
      Y( K) =  Y(K) - FMWLY
   30 CONTINUE
      DO 33 K = 1,N
      X(K) = X(K) * FLV
      Y(K) = Y(K) * WRV
   33 CONTINUE
   50 FORMAT (10F8.1)
      DO 31 I = 1,180
      DIFF(I) = 0.
      SUM(I) = 0.
      DO 41 K = 91,M
      IX = K + L - 90
      DIFF( K) =   X(K) - Y(IX))**2
      SUM(I) = SUM(I) + DIFF(K)
   41 CONTINUE
      L = L - 1
   31 CONTINUE
      WRITE(6,55)  SUM(I),(I = 1,180)
   55 FORMAT (5F12.3)
      END
```

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13. ABSTRACT

Four sets of field measurements were made of swell in and just seaward of the surf zone off a uniform sandy beach. Power spectra computed for both the pre-breakers and the foam lines revealed long waves associated with the swell having peak periods centered at approximately 80 seconds. Long wave records were produced by filtering out the ordinary swell through computing running means of the pre-breaker and foam-line records. Computer comparison of the long-wave records at the offshore and surf-zone sites for a given field run resulted in a time-correlation curve for various time lags between the records. Curves for all of the runs reveal that the long waves arrive from the open ocean, probably as forced waves travelling with swell groups, undergo reflection at the beach, and return back to sea as free waves.

DD FORM 1 JAN 64 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Long-period waves						
Surf zone						
Foam lines						

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